Indicator of risk of water contamination : methodology for the phosphorus component /

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INDICATOR OF RISK OF WATER CONTAMINATION: METHODOLOGY FOR THE PHOSPHORUS COMPONENT

PROGRESS REPORT

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Preface

The Indicator of Risk of Water Contamination (IROWC) is one component of Agriculture and Agri-Food Canada's Agri-Environmental Indicator (AEI) project. The overall objective of the project is to develop and provide information to help integrate environmental considerations into decision-making processes of the agri-food sector. The IROWC component measures progress in reducing the risk of water contamination from agricultural activities, focusing on crop nutrients (N and P). The work on an IROWC-P methodology started with a review of P losses from agriculture as a nonpoint source of pollution of surface waters, with emphasis on current work in the U.S. and eastern Canada. Details on this review are available in a manuscript entitled "Phosphorus losses in agricultural drainage: Historical perspective and current research" by Sims, Simard and Joern, accepted for publication in *Journal of Environmental Quality*.

This progress report contains a description of a proposed IROWC-P methodology applicable at the Soil Landscapes of Canada polygon level. The extension of this approach to other provinces and at other hierachical levels of application (e.g., farm level) is also being addressed. The progress report was produced on behalf of Agriculture and Agri-Food Canada's IROWC technical team: K.B. MacDonald (ON), P. Milburn (NB), R.R. Simard (QC), B. Bowman (ON), C. Chang (AB) and B. Zebarth (BC).

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Summary

The objective of this study is to propose a methodology for developing an Indicator of Risk of Water Contamination for phosphosous (IROWC-P) applicable at the Soil Landscape of Canada (SLC) polygon level (1:1 million map scale). The methodology will be tested on a pilot basis for the province of Québec. The extension of this approach to other provinces and at other hierachical levels of application (e.g., farm level) are also being addressed. The work on an IROWC-P methodology started with a review of phosphorus losses from agriculture as a nonpoint source of pollution of surface waters.

Phosphorus interacts more directly than N with soil particles throughout the soil profile. Phosphorus is buffered more strongly than N by the soil reacting surfaces although the two elements are strongly dependent on soil microbes for their cycling in agroecosystems. This implies that some of the assumptions made for the calculations within the IROWC-N methodology are not applicable to P. Therefore, it was considered that the most appropriate approach to derive IROWC-P estimates would be to adapt a Phosphorus Index (PI) that was developed in the U.S., and to incorporate as much information as possible from the IROWC-N methodology. The proposed approach should provide sufficient resolution to identify areas vulnerable to losses of P to surface waters at the SLC polygon level. However, several additional modifications will most likely have to be made to refine the ratings in the adapted PI. Data availability will largely affect the improvement, the adaptability and the limits of the current approach. The approach will remain flexible to incorporate regional differences in soil characteristics and climatic conditions. At this stage, the approach includes a soil erosion and a surface runoff component, an annual P balance component, and soil test P and P saturation levels. Information from a provincial survey will be used to estimate the two latter components.

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1. Introduction

The overall objectives of the AEI project are to:" *improve the understanding of the nature, extent, and location of environmental risks and benefits related to primary agriculture; track the agri-food sector's progress toward environmentally sustainable agriculture; support the design and targeting of agri-environmental strategies, policies, and programs and to help integrate environmental considerations into decision-making processes* " (Agriculture and Agri-Food Canada, 1997). The IROWC component measures progress in reducing the risk of water contamination from agricultural activities, focusing on crop nutrients (N and P).

The contribution of P from agriculture to the nonpoint source pollution of surface waters has been of environmental concern for a long time because of the well-known role of P in eutrophication of inland waters. The Québec Ministry of Natural Resources established its first network of river water quality monitoring in 1967. The results indicated total P concentrations (P_t) largely in excess of the 0.03 mg P_t L^{-1} provincial norm in most rivers (Bobée et al. 1977) and agriculture was held responsible for these elevated P_t levels (Grimard, 1990). Although some improvements have been achieved since 1979, P_t concentrations remain generally higher than the provincial norm (Painchaud, 1997).

The review of phosphorus losses from agriculture in parts of the U.S. and eastern Canada (Sims et al. 1997) pointed out that subsurface P losses may be an important component of the total P export from some agricultural watersheds. Therefore, this component should not be neglected when developing management strategies to minimize nonpoint source pollution of surface waters. It was also indicated that it would be particularly important to consider regions where subsurface transport is enhanced by artificial drainage systems, associated with areas where soil P concentrations have already reached very high levels and where soil P sorption capacities are low to moderate. It was also underlined that the environmental impacts of subsurface P losses from

leaching and transport to surface waters in tile drainage are not "*universal problems*", and that in many situations they will be of little consequence, relative to erosion and runoff. Therefore, if an erosion and runoff component is necessary for IROWC-P estimates in areas with significant slopes, a P leaching component is also required to fully assess P losses in imperfectly and poorly drained agroecosystems with flat topography.

The USDA-SCS has developped an indexing procedure to assess the impact of various landforms, soils and management practices on the potential risk of P movement to water bodies (Lemunyon and Gilbert, 1993). The indexing procedure uses characteristics such as soil erosion rates, runoff, distance to water body, vegetation, grazing, available soil test levels, P application rates, methods and timing. The Phosphorus Index (PI) can be used by conservation and environmental groups at different hierachical levels of application (e.g., farm, watershed). Researchers could use the index values to compare with model simulations. A similar approach can be developed in Canada including components from sediment and leaching transport to develop an adapted IROWC-P.

The objective of this study was to propose an IROWC-P methodology applicable at the Soil Landscape of Canada (SLC) polygon level (1:1 million map scale). The methodology will be tested on a pilot basis for the province of Québec. The extension of this approach to other provinces and at different hierachical levels of application (e.g., farm level) was also considered.

2. Suggested methodology for IROWC-P estimates

2.1. Background

The risk of water contamination from agricultural activity is affected by the type of farming system and management practices (e.g., animal or cash crop farms, monoculture or rotations). The IROWC calculations involve a partial budgeting approach to estimate the water balance and the concentration of potential contaminants (MacDonald and Spaling, 1995a; 1995b). This approach calculates (for each contaminant) the known inputs and outputs, and then assumes that the remainder is potentially available for transport into surface or groundwater (i.e., assuming that there is sufficient moisture to remove the contaminants in excess). In the water balance model, the quantity of surplus available water is estimated by calculating the difference between precipitation and potential evapotranspiration. The available water holding capacity is considered as a mixing volume for soluble contaminants and is calculated as a function of soil texture.

There are currently no factors in the Census of Agriculture (CoA) which directy relate to water partitioning. Therefore, no water partitioning was made at the regional level in the IROWC-N calculations (MacDonald and Gleig, 1996). This exclusion was considered as reasonable in areas where the predominant pathways for excess water are through the rooting zone to subsurface drains or to groundwater. A water partitioning considers the proportion of water available from precipitation (and irrigation) which is not lost through evapotranspiration and leaves the agroecosystem by surface runoff, tile flow or groundwater recharge.

Phosphorus interacts more directly than N with soil particles throughout the soil profile. These interactions are dependent upon biological, physical and chemical soil characteristics. Phosphorus is buffered more strongly than N by the soil reacting surfaces although the two elements are strongly dependent on soil microbes for their cycling in the agroecosystems. Therefore, some of

the assumptions made for the calculations within the IROWC-N methodology are not applicable to P. This implies that several modifications to the IROWC-N methodology are necessary before it could be completely applicable to P.

For example, IROWC-P calculations would ideally require both a water balance and a water partitioning (i.e., infiltration and runoff water), as well as an estimate of water delivery (e.g., runoff water reaching surface waters). The review on P losses from agriculture (Sims et al. 1997) indicates that there are at least two hydrologic pathways involved in the subsurface transport of P from soil to water: "*The first is the gradual, downward movement of P in percolating waters that interact with the bulk of the soil profile and eventually with tiles or subsurface water flowing laterally and discharging into ditches or streams*", "*The second is bypass flow, the rapid movement of dissolved and particulate P via macropores that extend from the soil surface to tile drains or subsoil horizons where accelerated lateral flow to surface waters occurs*". The concentration of P in this excess water depends on the soil P content and its interaction with soil surface particles (P saturation) in each layer of the soil profile.

In regard to P, estimates for erosion induced sediment or particulate P losses and delivery rates to surface waters would also be necessary. Sediment transport and delivery to surface waters can not be estimated with soil loss prediction models, only the rate of soil movement off a particular field slope can be estimated (Wischmeier and Smith, 1978). The amounts of sediments transported off the field to a water body is only a fraction of that eroded from the slope. The development of process models for erosion prediction would improve the predictability of the sediment delivery ratio off-site the field (Nearing et al., 1990; cited by Lemunyon and Gilbert, 1993). Although work on this matter is under way for erosion induced sediment delivery rates (Nearing et al. 1990, cited by Lemunyon and Gilbert, 1993). These process models are not ready for routine use and widespread application (RUSLEFAC, 1997). It is also anticipated that an important research issue in the future will be to define the main P transport processes related to subsurface flow. The relative importance

of how the latter vary seasonally or in response to changes in management practices will also have to be addressed (Sims et al. 1997). Furthermore, different forms of P may have potentially different impacts on the biological productivity of P-sensitive surface waters. For example, compared to particulate P or sediment-bound P, the loss of total P predominantly as dissolved P could have a greater impact on the biological productivity of P-sensitive surface waters since dissolved P is immediately available for algal uptake (Sharpley, 1995a).

Therefore, it was considered that the most appropriate approach to derive IROWC-P estimates would be to adapt a Phosphorus Index developed in the U.S. and to incorporate as much information as possible from the IROWC-N methodology. This approach, its extension to other provinces and its application to other hierachical levels of application (e.g., farm level) is briefly described and discussed in the following sections.

2.1.1. Description of the Phosphorus Index

The indexing procedure to assess the impact of various landforms, soils and management practices on the potential risk of P movement to water bodies was initiated by Lemunyon and Gilbert (1993). The Phosphorus Index (PI) has been tested in Oregon and Washington (Stevens et al. 1993), in Georgia (Truman et al. 1993), and in Oklahoma and Texas (Sharpley, 1995a). It has also received some attention by agrononomists from the Québec Ministry of Agriculture (Giroux et al. 1996).

According to the concept and philosophy of the index, a ranking with the PI identifies sites where the *potential risk* of P movement may be *relatively* higher or lower than other sites. The latest version of the phosphorus risk index also addresses its potential to serve as a tool both for the determination of best management practices necessary to control P movement, and as a measure in the change of risk over time as a function of changes in management practices (USDA-NRS, 1997). However, a ranking of a given site with the PI is not intended as a quantitative measure of the degree of compliance with water quality standards or as a potential tool for regulatory purposes.

The PI is a two dimensional 9 by 5 matrix using a limited number of landform site characteristics. The two-dimensional matrix relates the field site characteristics to categories which indicate a potential degree of P movement. Each of the site characteristics is assigned a weighting factor based on the potential for that characteristic to affect P movement. The nine site characteristics and their respective weighting factor are shown in Table 1.

Table 1. Site characteristics and suggested weighting factors in the latest version of the PI (USDA-NRS, 1997).

Site Characteristic	Weighting factor
P application rate	2.0
Soil test P	2.5
Distance to water body	2.0
Erosion rate	1.0
Runoff potential	2.5
P application method	1.0
P application timing	1.0
Vegetation	1.5
Grazing	2.0

Value categories are defined as measured (or estimated) levels of each site characteristic. The higher the value the greater is the potential for phosphorus losses. Five value categories for each site characteristic with a rating system using base of 2 are used; Very low (1), Low (2), Medium (4), High (8) and Very High (16). To make an assessment using the PI, a rating value is measured (or estimated) for each site characteristic using the above-mentioned categories. The rating value of the corresponding category is then multiplied by the site characteristic weighting factor to get a weighted value for each characteristic. The weighted values are then summed for all site characteristics and compared to a site vulnerability chart (Table 2).

Table 2. Site vulnerability ratings and interpretations (USDA-NRS, 1997).

Total of weighted rating values	Site vulnerability class
15 - 22	Very low
23 - 46	Low
47 - 93	Medium
94 - 186	High
187 - 248	Very high

2.1.2. Modifications to the Phosphorus Index for the SLC polygon level

2.1.2.1. Erosion and runoff

Although it was recognized that subsurface flow may be important in specific cases, the PI considers that soil erosion and surface runoff are the only mechanisms of P movement to surface waters. Lemunyon and Gilbert (1993) suggested that soil erosion can be estimated with existing prediction models. The USLE (Wischmeier and Smith, 1978) or RUSLE (Renard et al. 1993) models were suggested for water erosion and the WEQ (USDA-SCS, 1988) model for wind erosion.

For Québec (and for other Canadian provinces), the Revised Universal Soil Loss Equation For Application in Canada (RUSLEFAC, 1997) model will be used to estimate soil erosion loss value categories. This model is part of the Indicator of Risk of Soil Degradation (including soil erosion, soil organic matter and soil compaction) and takes into account climate, topography, land use practices, soil and vegetation or crop. RUSLEFAC estimates the amount of soil loss that results from sheet or rill erosion on a single slope, but does not account for additional soil losses that might occur from gully, wind or tillage erosion. The model estimates five different soil erosion classes (Table 3). Calculations for soil erosion losses with this model have been initiated for the Québec province at the SLC polygon level.

Table 3. Soil erosion classes estimated with RUSLEFAC.

Soil erosion class	Potential soil loss (T ha^{-1} yr^{-1})
Very low	< 6
Low	6 - 11
Moderate	11 - 22
High	22 - 33
Severe	> 33

In the PI, the surface runoff potential can be estimated using a matrix relating percentage of slope with runoff curve numbers (or with soil permeability classes). The matrix relating runoff curve numbers with percentage of slope to estimate the risk for runoff were slightly modified in order to match the slope classes available in the SLC database (Table 4). The runoff curve number can be determined from a sub-matrix using information on land use, cover, condition and hydrologic group information (adapted from USDA-SCS, 1972). The following assumptions were made in order to adapt this sub-matrix to the SLC polygon level and in order to match Census data: i) the cover treatment practice was always considered straight row, ii) the cover hydrologic condition was always considered as good, and iii) the runoff curve numbers will be estimated using a weighted average of the crops present within a given SLC polygon. Soil hydrological groups are estimated by SLC drainage classes (Table 5).

Table 4. Adapted matrix relating runoff curve numbers with SLC slope classes to estimate runoff risk classes.

	Runoff curve number				
Slope	< 50	50-60	60-70	70-80	> 80
0 - 3%	Very low	Very low	Very low	Low	Moderate
4 - 9%	Very low	Very low	Moderate	High	High
10 -15%	Very low	Low	Moderate	Very high	Very high
> 15%	Very low	Low	High	Very high	Very high

Table 5. USDA-SCS Soil hydrological groups estimated with SLC drainage classes.

SLC Drainage Class	USDA-SCS Soil Hydrological Group
Excessively	A
Rapid	A
Well	B
Moderately	B
Imperfectly	C
Imperfectly with rooting depth < 20 cm	D
Poor with rooting depth > 75 cm	C
Poor with rooting depth < 75 cm	D
Very poor	D

2.1.2.2. Annual P balance

The PI uses four field site characteristics that are related to the history and probable future additions of P and characterizes the means by which those additions will be made (Pierzynski and Logan, 1993). These characteristics are soil test P levels, P application rate (i.e., manure and fertilizer P), P application method and timing. These four site characteristics could be integrated into an annual P balance (although it may only be possible to partly take into account P application method and timing). This annual P balance will be calculated by adapting the methodology developed for the IROWC-N estimates to include calculations for P. Three parameters will be derived from the annual P balance: 1) crop residue, 2) P applied as mineral fertilizer, and 3) P applied as manure. The crop residue component will be expressed as a percentage of plant biomass left at the soil surface after harvest, the manure and mineral fertilizer P inputs will be expressed as a percentage of plant biomass P exports ((input / output) x 100).

It was assumed in the IROWC-N annual nutrient balance that the recommended N rate applied from fertilizer was equivalent to crop requirements. Therefore, it was not necessary to take into account the crop yields in order to calculate the annual N balance. For P, this assumption can not be made since the amount of mineral P applied is a function of soil test P levels and is often larger than crop removal. Thus, for the annual P balance, the amount of P exported by the crops will be estimated using average yield data. Average yield for Québec can be obtained from provincial census data (or from the Land Potential Database for Canada). Information on the quantity of P exported by the crops (as a function yield) will be obtained using coefficients from the Canadian Fertilizer Institute.

In Québec, Mehlich III extractable P and, for forages, the Mehlich III extractable Al are considered for fertilizer P recommandation (CPVQ, 1996). Fertilizer P application rates will be estimated for each crop type using information on the status of current soil test levels in Québec. This information is available from a provincial soil survey (Tabi et al. 1990).

The manure will basically be distributed over the farm area using the same principles and assumptions as for the IROWC-N calculations. Manure application rates are being determined as a function of crop N requirements. Briefly, the major assumptions that were made with the IROWC-N methodology are as follows: N availability in the year of application is determined according to animal categories; N from manure is applied at a maximum of 75% of the crop requirement; improved pasture receives cattle manure at up to 50% of the manure production level or up to the full N requirement for grass pasture; unimproved pasture receives cattle manure at up to 33% of the manure production level or up to 50% of grass requirement for N. Remaining manure (excess) is applied predominantly to corn, starting with silage corn then grain corn, 25% of the remaining manure is reserved to be distributed to hay and spring cereals because of timing for field application.

For Québec, P availability from manure could be calculated according to considerations from CPVQ (1996). However, even if provincial availability coefficients are used for different types of manures (i.e., differences between species and between solid and liquid manure), a compromise will have to be made in order to match these with the information on manure distribution that can be derived at the SLC polygon level. At the SLC polygon level, census data (1991) are available on the number of animals within each of the following categories: Poultry; Dairy cattle (cows, heifers and bulls); Beef cattle (cows, heifers and bulls); Slaughter cattle (slaughter and feeders + steers); Calves; Pigs and Other livestock (sheeps, horses, mink and fish). But, there is no distinction on whether it is handled in liquid or solid form. For the above-mentioned categories, P coefficients (kg P produced/year/animal unit) will be derived using provincial census data on the number (distribution) of animals within each of these categories.

In the fertilizer recommendations for Québec, an availability reduction factor is considered for manure applied in the fall (i.e., an available P reduction of 37.5%). It can be hypothesized that 50% of the manure is applied in the fall and that 50% is spring-summer applied. Therefore, the P availability coefficients from manure will be reduced by about 18% (i.e., 37.5% / 2). The amount of mineral fertilizer P will be reduced according to the amount of manure P applied. When manure P additions are in excess of recommended P application rates there would be no mineral fertilizer P applied, with the exception for corn where a minimum amount of 9 kg of P ha^{-1} would be applied as a starter fertilizer. As for N fertilization inputs, verifications will be made according to census information on fertilizer sales. Eventually, the above-mentioned assumptions may have to be reconsidered in order to match the census information to fertilizer sales. Furthermore, future manure allocations may be based on P on all P-rich soils since recent regulations on that matter are now in place in Québec (MEF, 1997). Briefly, this regulation stipulates that where soil test P levels are considered as rich or excessively rich, total P inputs (manure and mineral fertilizer P) can not exceed total P outputs.

2.1.2.3. Subsurface component

As previously discussed in the introduction, P leaching cannot be ignored in some agroecosystems and a subsurface component will be introduced in the PI. This component could be estimated based on the degree of soil P saturation. The P sorption capacity of a soil can be defined as the capacity of a soil to retain P according to different physical and chemical mechanisms. The soils in Québec differ in their natural P sorption capacity, because of differences in their physico-chemical characteristics according to parent material and soil-formation factors. Generally, the clayey Gleysolic soils in the Saint-Lawrence lowlands possess a weak to medium P sorption capacitiy, whereas the Podzolic soils in the Laurentian and Apalachian regions are characterized as having a medium to very high P sorption capacity (Giroux et al. 1996).

The Netherlands have a national strategy to limit the P entry into both surface and ground water. This strategy is based on the identification of a soil P saturation level above which P application should not exceed the amount of P exported by crops (Breeuwsma and Silva, 1992; Sharpley, 1995b). The rationale behind the P saturation approach is that soil P desorption increases as sorbed P accumulates in soil following P additions, enhancing P losses from runoff or leaching. This degree of accumulation is related to the degree of P sorption saturation (%) which is defined as: P sorption saturation = Extractable soil P / P sorption maximum. For noncalcareous soils, oxalate extractable P, Al and Fe are used in the Netherlands to estimate the extractable soil P and P sorption maximum. In the Netherlands, a P sorption saturation of 25% is considered as the critical value above which the potential for P movement becomes unacceptable. However, this critical value depends on the water quality standard limits and on the physical and chemical properties of the studied soil horizon (Beauchemin et al. 1996).

Although further work is needed to generalize critical values for a broad range of soil physical and chemical properties, the P saturation represents today a reasonable approach. In the U.S. and Québec, the degree of P sorption saturation has been found to be a potentially useful

environmental indicator (Sharpley, 1995b; Giroux and Tran, 1996; Beauchemin, 1997). In Québec, the P sorption saturation may be estimated by the ratio of Mehlich III extractable P / Mehlich III extractable Al in where both contents are expressed in mg kg^{-1} (Giroux and Tran, 1996). For Québec, these parameters are available at the soil series level from a provincial soil survey (Tabi et al. 1990). A linkage at the soil series level between the provincial dataset and the SLC database will be made so that this component can be estimated at the polygon level.

Giroux et al. (1996) suggested four different risk classes according to the degree of P sorption saturation for cultivated surface soils in Québec. Yet, the risk for P movement down the soil profile towards tile drains may also be dependent on subsoil properties (i.e., B horizon). The provincial survey by Tabi et al. (1990) contains information that allows an estimation of the soil P saturation levels down to the 60 cm depth. This information permits an estimation on the status of the subsoil P saturation levels. Based on this information, the risk classes suggested by Giroux et al. (1996) were modified as follows (Table 6). For soils with a low subsoil P sorption capacity (i.e., P saturation > 10%) the risk class is increased by one level.

Table 6. Degree of surface P saturation and associated risk classes.

P saturation[z]	Risk class
0-2.5%	Very low
2.5-5 %	Low
5-10 %	Medium
10-20 %	High
> 20 %	Very high

[z]Estimated by (Mehlich III P / Mehlich III Al) x 100; for soils with low subsoil P sorption capacity (P saturation > 10%) the risk class is increased by one level.

2.1.3. Discussion of the adapted Phosphorus Index (IROWC-P) for the SLC polygon level

The adapted PI (Table 7) would give an indication of both the risk for P losses from soil erosion, surface runoff and subsurface flow. Soil test P levels are considered in the PI to assess the potential eutrophication of nearby surface waters. Although this parameter does not give any quantitative information on P delivery, it is assumed that, generally, there may be potential environmental problems when soil test P levels reach high to excessively high levels (Sharpley et al. 1993; Sims, 1993).The major environmental issue related to high soil test P levels occurs for areas with animal waste-amended soils (Sims, 1993). Soil test P levels exceeding crop requirements have been reported for areas in Québec with high livestock densities (Simard et al. 1995; Tabi et al. 1990). High soil test P levels may also be found for areas under intensive monoculture of crops with high nutrient requirements (e.g., corn) (Tabi et al. 1990).

Table 7. Adapted Phosphorus Index (IROWC-P) for the SLC polygon level.

	Phosphorus loss rating (value)				
Site characteristic (weight)	Very low (1)	Low (2)	Medium (4)	High (8)	Very high (16)
- Soil erosion (1.0)[z]	< 6	6-11	11-22	22-33	> 33
- Runoff potential (2.5)	Very low	Low	Moderate	High	Very high
- P saturation (2.0)[w]	0-2.5	2.5-5%	5-10%	10-20%	> 20%
- P soil test (2.5)[k]	< 60	60-150 ·	150-250	250-500	> 500
Annual P balance					
- Crop residue (1.0)	< 2%	2-5%	5-20%	20-50%	> 50%
- Manure (2.0)[y]	< 50%	50-100%	100-150%	150-200%	> 200%
- Fertilizer (1.0)[y]	< 50%	50-100%	100-150%	150-200%	> 200%

[z]Soil erosion losses in T ha^{-1} . [y]Expressed as a percentage of plant biomass P exportations.[w] (Mehlich III P / Mehlich III Al) x 100; for soils with low subsoil P sorption capacity (P saturation > 10%) the P loss rating value is increased by one level. [k]According to Mehlich III extractable P in kg P ha^{-1} (adapted from Giroux et al. 1996).

The degree of P saturation is related to soluble soil P levels and thus to the potential for P loss in runoff or leaching (Giroux et al. 1996; Sims et al. 1997). Therefore, when the P saturation reaches a given level there is a greater risk of downward movement of P in the soil profile. Increasing soil test P levels is also an indication of the potential for subsurface P losses. As suggested by Beauchemin et al. (1996), the combination of a measure of soil P sorption capacity (e.g., degree of P saturation) and a measure of desorbability (e.g., soil test P) could be an accurate approach to fully assess the risk of contamination of drainage waters by P leaching. It was shown that the P saturation alone cannot predict the P content in surface runoff or drainage water (Simard et al. 1998).

Soil test P levels in surface soils can be correlated with the concentration and loss of P in runoff. A highly significant linear relationship has been reported between surface soil test P levels and the amount of dissolved P in surface runoff (Hanway and Laflen, 1974; Romkens and Nelson, 1974; Sharpley et al. 1978; 1981; Oloya and Logan, 1980, cited by Sharpley et al. 1993). However, this relationship may differ between soils. The P saturation may give a better indication of the potential for runoff P losses (Sharpley, 1995b). The soil test P level is also related to sediment P losses, the enrichment in the eroded sediments being greater with high soil test P levels (Lemunyon and Gilbert, 1993).

The degree of P saturation may be estimated using different methods or type of extractants. For example, in some OECD countries, ammonium oxalate extractable Al and Fe are used as an estimation for P sorption capacity. A predictive equation for P sorption capacities from soils of the Beaurivage watershed was developped by Simard et al. (1994a). It is possible that such an approach is more accurate than using Mehlich III extractable P and Al, although this issue needs further research. In particular, the importance of Fe in the P sorption capacity of some gleysolic soils should be better assessed. Meanwhile, there is a clear advantage of using the Mehlich III-P / Mehlich III-Al saturation index for Québec, as both variables are available in the provincial soil survey.

The annual P balance integrates different management impacts such as crop type, rotations, fertilizer application rates and manure management, which are recorded periodically in the CoA. The amount of P inputs increases the risk of P losses to surface waters both from soil erosion and runoff, and subsurface flow (Lemunyon and Gilbert, 1993; Pierzynski and Logan, 1993; Sims et al. 1997).

In Québec, the P fertilizer recommendation program (Giroux and Tran, 1994; CPVQ, 1996) has the following objectives: (1) P fertilizer will balance P exports for soils having medium to adequate P fertility; (2) for soils with low soil test P levels, fertilizer P will aim at increasing soil test P values to reach a medium to adequate level; (3) for rich soils, fertilizer P applications are made below P exports in order to reduce soil test P values to reach a medium to adequate P fertility level; (4) for excessively rich soils, only a small quantity of P is recommended for some crops as a starter fertilizer. According to such recommendations, since fertilizer P applications calculated by the IROWC-P approach are made with reference to current soil test P levels, the amount of fertilizer P applied is considered less risky than manure applied P. It is considered that P from manure (P in excess of crop requirements occurs mostly when large quantities of manure are applied) is a more important risk factor. Furthermore, as mentioned earlier, the situation most commonly associated with P leaching has been the long-term manure applications. Therefore, the site characteristic weight value is higher for manure P (2.0) than for mineral fertilizer P (1.0).

Data in Québec suggest that, on average, Mehlich III P concentrations will increase between 0.25 to 0.5 units per unit of applied P (Giroux and Tran, 1994). However, this relationship depends on the soil clay content. Cox (1994) showed that the increase in Mehlich III P per unit of applied P ranged from less than 0.2 for soils with low (< 10%) to 0.7 for soils with high (> 50%) clay content, respectively. The type of primary tillage (reduced vs moldboard plow) will also have a large influence on this Mehlich III P rate of increase by unit of P fertilizer applied (Simard et al. 1994b). Although these relationships may not be applicable to all kind of soils and situations, the annual P balance may also be used to make a "rough" estimate of the change in soil test P levels over the

years.

The weighted values for each Soil Landscape of Canada polygon level will be compared to a modified vulnerability chart (Table 8). The limits of the vulnerability risk classes of P losses to surface waters for each SLC polygon were derived using the same method as the USDA-NRS (1997). These risk classes will be reevaluated if further site characteristics are included in the adapted PI.

Table 8. Site vulnerability ratings and interpretations obtained from the summation of the weighted products using the adapted PI for each SLC polygon.

Total of weighted rating values	Site vulnerability class
12 - 18	Very low
19 - 36	Low
37 - 72	Medium
73 - 144	High
145 - 192	Very high

2.1.4. Extension of the Phosphorus Index to other provinces and at other hierachical levels of application

The currently used and potentially useful parameters with the PI at different hierachical levels of application are presented in Table 9. Two hierachical levels of investigation were considered: (1) the SLC polygon level, which is the proposed IROWC-P methodology to be tested on a pilot basis for Québec, and possibly extended to other provinces; (2) the field level which could be applicable at the farm or watershed level.

SLC Polygon level

For Québec, it is possible to include soil test P levels and a P saturation component from a provincial soil survey in the PI. For other regions in Canada, detailed provincial surveys may not be available. A preliminary investigation on soil test P data availability for the prairies suggests that there is probably no central database available in Alberta and Manitoba. For Saskatchewan there may be some data available, although it may be difficult to match these with the SLC polygons. For the Maritimes there may be some possibility to have soil test P data from 1993 up to the present (likely Mehlich III) for PEI. Yet, the degree of representativity and the possibility to match these data at the SLC polygon levels require further investigation. However, a geographical (by a certain grid) sampling program on soil test P levels will be initiated in 1998 to cover all the PEI, and thereafter sampling will be done every three years. In any case, the availability of soil test P data for other provinces needs to be investigated more thoroughly.

Furthermore, estimates of P saturation degree using Mehlich III extractable P and Al may not be appropriate for all types of soils. Fertilizer recommendation strategies may also vary and be based upon other extractants than Mehlich III (e.g., Bray 1, Olsen etc). For example, soils on the prairies are in many cases considered as deficient in nutrients (N and P) and require annual inputs of nutrients for optimal crop growth. The calcareous nature of these soils often restricts inorganic P mobility. Nevertheless, inadequate manure management may still pose a risk of P contamination of

surface waters through surface runoff on sloping lands. Furthermore, excessive manure application could also increase the risk of downward movement of organic P to shallow aquifers areas (Simard et al. 1997).

Table 9. Parameters and data sources used with the PI at different levels of investigation.

Level of investigation	Parameters		Data sources
	Current	Potential	
SLC Polygon Province	- Soil erosion - Runoff potential - P saturation - Soil test P - Annual P Balance (Crop residue P) (Manure P) (Inorganic P)	- Water balance - Drainage system - Distance to water body - Soil cracking	Census (Agriculture) USLEFAC Provincial Surveys Climatic Normals
Field Farm Watershed	- Soil erosion - Runoff potential - P saturation - Soil test P - Annual P balance - Distance to water body - P application method - P application timing - Vegetation - Grazing	- Water balance - Drainage system - Soil cracking - Type of crop (perennial vs annual) - Tillage practices (macro- bio-pores) - Type of manure (solid vs liquid) - Landuse (cropland, woodland, etc)	RUSLE type model Climatic Normals Detailed Soil Maps Farmers[z] Agronomists[w]

[z]e.g., Producer records. [w]e.g., Fertilization plans.

However, losses of subsurface P other than by preferential flow in water-deficient regions are less likely to occur and this will have to be considered when extending the approach to such areas. For that purpose, it may be appropriate to include the water balance (used with the IROWC-N methodology) as a site characteristic to determine the potential for leaching (i.e., surplus water or not). The presence of subsurface drainage systems which may act as preferential channels to surface waters could also have to be considered. The distance to water body would also be an important characteristic for some areas and could possibly be used at the SLC polygon level. Finally, preferential flow through soil cracks which would occur mainly on clayey soils following a long period of drought is another parameter that could eventually be included at the SLC polygon level. Information on soil texture, mineralogy and climatic conditions could be used for that purpose. Data on mineralogy is partly available in a document produced by Kodama et al. (1993). However, the mineralogy of the surface horizon of Québec soils was found to be fairly constant for large areas (Simard et al. 1991).

Farm or Watershed level

One of the applications of the PI is as a tool for field staff working with landusers to identify vulnerable areas and recommend management alternatives to decrease the risk of P losses (Lemunyon and Gilbert, 1993). These so called "Best Management Practices" (BMP's) are one of the strategies that may be applied to a farm or watershed in order to reduce the risk of P movement to surface waters. Generally, the BMP's would be applied at the field level on individual farms within a watershed. Although some broad level sources of information may be useful (e.g., erosion models, climatic normals), the main source of information will have to come from the local level in order to be as detailed and field-specific as possible (e.g., producer records, fertilization plans). Therefore, BMP's will have to be developed in close collaboration with the farmers and local agronomists.

There are more parameters that are currently used or could potentially be included in the PI at the field level than at the SLC polygon level. Generally, these parameters are more management

related, such as P application method and timing, type of manure and tillage practices. However, all these parameters do not necessarily apply to all situations. The parameters listed as being potentially useful are suggestions and not a complete list of what kind of information that may be necessary for any specific condition. For example, preferential flow through soil cracks and macropores can be dependent upon management. Tillage practices influence the network of biopores and soils under permanent no-till or forage production may be at high risk of P leaching, particularly if liquid manure is applied (Sims et al. 1997).

Stevens et al (1993) applied the PI to different conservation field trial treatments in western Oregon. The results suggested that the PI was sensitive to nutrient management factors (e.g., soil test P, P application rates and methods), but less sensitive in differentiating sites based on the transport factors (i.e., erosion and runoff). Sharpley (1995a) used the PI for 30 watersheds in the Southern Plains area of Oklahoma and Texas. A significant relationship was found between watershed vulnerability to P loss in runoff and actual losses measured over the last 16 years (r=0.70**). Although the PI has been tested with some success further testing and validation are necessary both at the research plot and field/watershed levels. For instance, the PI has not been tested or validated for Canadian conditions. This is particularly important when adapting the PI to local conditions in order to suggest the most appropriate BMP's.

3. Future directions

The adapted PI contains a soil erosion and a surface runoff component, an annual P balance, soil test P and P saturation levels. The major modifications made to the PI was the inclusion of the soil P saturation level. The proposed approach should provide sufficient resolution to identify areas vulnerable to losses of P to surface waters at the SLC polygon level. However, several additional modifications will most likely have to be made to refine the ratings in the adapted PI.

A key issue will be to ensure that the input data used in the approach are being recorded periodically, or, that a periodical change can be estimated from other input data, so that the progress in reducing the risk of water contamination from P can be assessed as thoroughly as possible. Therefore, data availability will largely affect the improvement, adaptability and the limit of the current approach. The approach will have to remain flexible to take into account the regional differences in soil characteristics and climatic conditions.

Some validation will be carried out on specific SLC's from which values of water quality are available. This may help to select or confirm the weight values associated with the parameters. Furthermore, a base year can be selected (1991 for Québec) and the trends of risk (as indicated by the index) can be examined with respect to the base year. The sensitivity of the index to soil test P levels and P saturation will be examined for Québec in order to provide an indication of how well an adapted approach could perform in regions of Canada where these data are not available.

It will also be important to closely follow the current development of process based prediction models which may enhance the possibility to quantify some of the processes involved in P losses and transport to surface waters. This could permit a greater similarity between the IROWC-P and IROWC-N indicators.

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